Dynamical coupled-channel study of $K^+\Lambda$ photoproduction

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Results for the reaction $\gamma p \to K^+\Lambda$, studied within a constituent quark model and a dynamical coupled-channel approach, are presented and compared with recent data. Issues related to the search for missing baryon resonances are briefly discussed and the role played by a third S_{11} resonance is underlined.

1. INTRODUCTION

The electromagnetic production of associated strangeness on the proton in the total center-of-mass range from threshold up to $W \approx 2.3$ GeV is under extensive study both experimentally and theoretically. Besides understanding the elementary reaction mechanism, a strong motivation is the search for the missing baryon resonances and improved insights into the known ones.

The quality of recent data [1, 2, 3, 4, 5] requires going beyond the direct production channel, by taking into account intermediate and final state interactions (FSI) [6, 7, 8]. In an earlier paper [6], it was reported that coupled-channel (CC) effects are significant at the level of inducing up to 20% changes on total cross sections. In this latter investigation the direct (without CC effects) channel $\gamma p \to K^+\Lambda$ was described via a very simple effective Lagrangian model, which embodied only two baryon resonances. The present work takes advantage of a comprehensive chiral constituent model (CQM) [9], which includes all known baryon resonances. Moreover, for the CC effects, here we use a more advanced model [7] for meson-baryon interactions to take into account the multi-step processes such as $\gamma N \to \pi N \to KY$ and $\gamma N \to KY \to KY$.

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2. THEORETICAL FRAME

Here we recall very briefly how the direct $K^+\Lambda$ production, via a CQM, and the CC approach, accounts for strangeness production including $KY \rightarrow KY$ FSI, as well as $\pi N \rightarrow KY$ and $KY \rightarrow KY$ intermediate state interactions (ISI); with $Y \equiv \Lambda, \Sigma$.

2.1. Direct channel: chiral constituent quark formalism

The low energy QCD Lagrangian is the starting point of this approach to pseudoscalar meson photoproduction on nucleons, based on the $SU(6) \otimes O(3)$ symmetry. The present work goes beyond the exact $SU(6) \otimes O(3)$ symmetry by introducing [9] the configuration mixing generated by gluon exchange interactions [10].

The advantage of the quark model is the ability to relate the photoproduction data directly to the internal structure of the baryon resonances. It also allows one to introduce in the reaction mechanism *all* known nucleon (s-channel) and hyperon (u-channel) resonances.

This formalism is proven [9] to produce realistic direct channel models in good agreement with the data for both $\gamma p \rightarrow \eta p$ and $\gamma p \rightarrow K^+\Lambda$ processes and shows the need for a third S_{11} resonance.

2.2. Coupled-channel intermediate and final state meson-baryon interactions

The intermediate state reactions ($\pi N \rightarrow KY$ and $KY \rightarrow KY$) are studied [7] using a dynamical coupled-channel model of meson-baryon interactions at energies where the baryon resonances are strongly excited. The channels included are: πN, $K\Lambda$, and $K\Sigma$. The resonances considered are: N^* [$S_{11}(1650)$, $P_{11}(1710)$, $P_{13}(1720)$, $D_{13}(1700)$]; Δ^* [$S_{31}(1900)$, $P_{31}(1910)$, $P_{33}(1920)$]; Λ^* [$S_{01}(1670)$, $P_{01}(1810)$]; Σ^* [$P_{11}(1660)$, $D_{13}(1670)$]; and $K^*(892)$.

The basic non-resonant $\pi N \rightarrow KY$ and $KY \rightarrow KY$ transition potentials are derived from effective Lagrangians using a unitary transformation method. The dynamical coupled-channel equations are simplified by parametrizing the $\gamma N \rightarrow \pi N$ and $\pi N \rightarrow \pi N$ amplitudes in terms of empirical πN partial-wave amplitudes [11] and a phenomenological off-shell function. A model has been constructed with the coupling constants and resonance parameters consistent with the SU(3) symmetry and/or the Particle Data Group values [12]. Good fits to the available data for $\pi^- p \rightarrow K^\circ\Lambda$, $K^\circ\Sigma^\circ$ have been achieved [7].

3. RESULTS AND DISCUSSION

We focus on the interpretation of recent data from the CLAS Collaboration [1], embodying all 920 measured differential cross sections [2] in our data-base. This latter has been fitted, using the CERN MINUIT package. The free parameters are those of the CQM (mainly one $SU(6)\otimes O(3)$ symmetry breaking parameter per nucleon resonance with $M \leq$ 2 GeV). Parameters for the intermediate and final state meson-baryon interactions are taken from the model B in Ref. [7].

Results for the differential cross section at three angles are shown in Figure 1. The full curves come from our complete model, embodying all relevant ISI and FSI, and reproduce the 920 data points quite well. In order to emphasize different effects in the reaction under

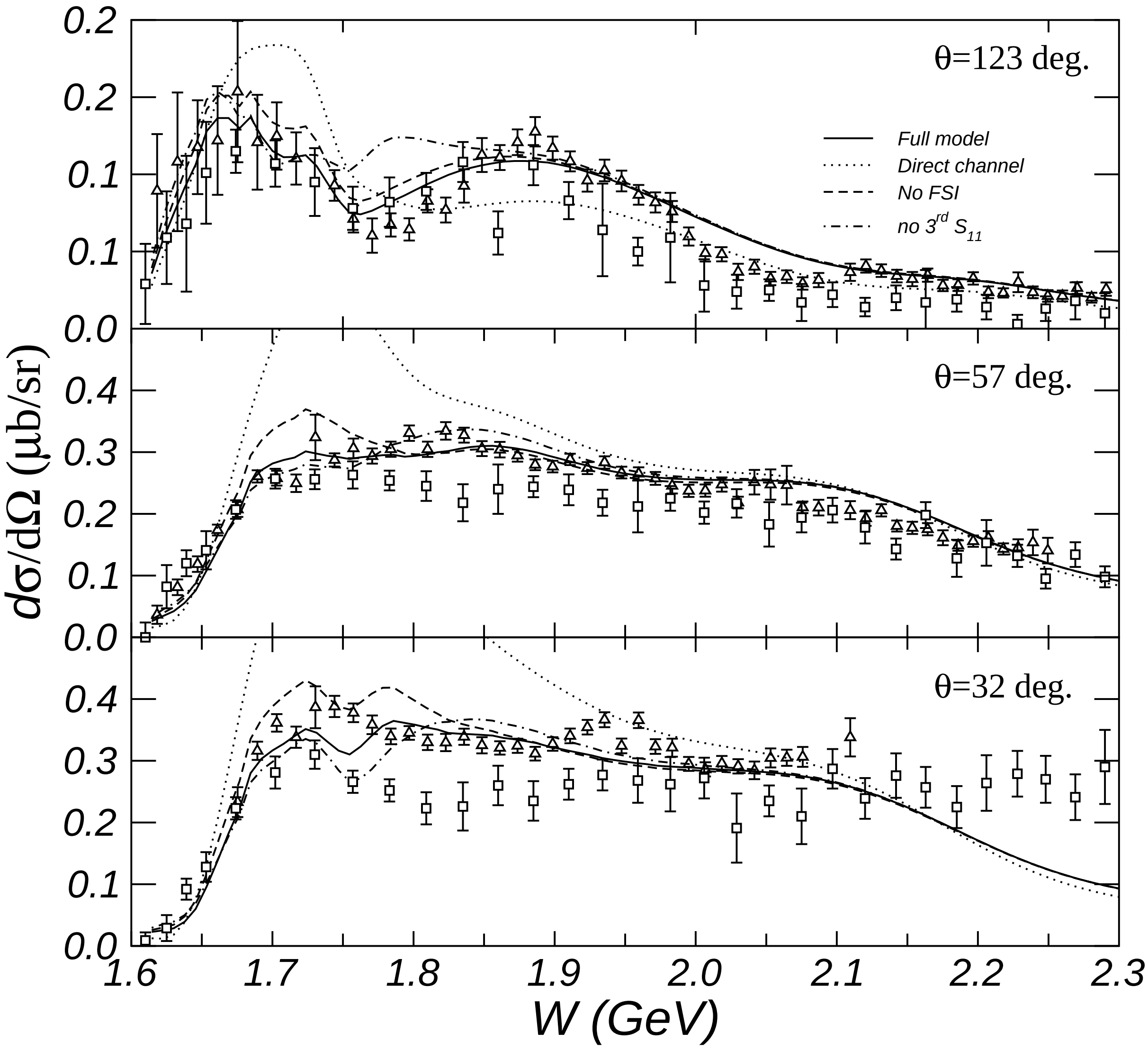

Figure 1. Excitation functions as a function of total center-of-mass energy at $\theta = 32°$, $57°$ and $123°$. Full curves: complete results (CQM+CC). Dotted curves: direct channel (without CC effects). Dashed curves: full calculation, but without final state $KY \to KY$ interactions. Dot-dashed curves: full calculation, but without the third S_{11}resonance. Fitted data (Triangles) are from CLAS [1]. SAPHIR data [3] are also depicted (Squares).

study, three other curves are depicted. They are obtained without further minimizations, but only by swicthing off some of the parameters related to specific contributions.

The dotted curves (Direct channel), are obtained by switching off the coupled-channel interactions, keeping hence only the direct channel contributions. The sizeable effects observed in the second resonance region show clearly the crucial role played by the CC phenomena.

The dashed curves (No FSI) come from the CC effects only due to the intermediate $\pi N \to \pi N$, KY interactions. Here final state $KY \to KY$ are discarded. The results show very significant contributions from the ISI. As expected, the FSI are less important, but they are not negligible.

Going back to the full model, we have switched off the third S_{11} resonance, see the dot-dashed curves. Significant contributions, especially at the most backward angle, are observed around 1.8 GeV. The extracted values for the mass and the width of this resonance, via the minimization procedure, are $M \approx 1.780$ GeV and $\Gamma \approx 100$ MeV, respectively. Those values agree with our previous findings [9], as well as other results reported [13] in the literature.

We have also investigated possible contributions from a third P_{13} missing resonance, but found no significant effects.

Concerning the data-base, the significant discrepencies between the CLAS [1, 2] and SAPHIR [3] Collaborations does not allow a simultaneous fitting of both data-sets. However, fitting seperately the SAPHIR data, leads to slightly different free parameters, but to comparable conclusions on the effects investigated via the curves shown in Fig. 1. The existing and forthcoming polarization data [1, 2, 3, 4, 5] will, hopefully, clear up those experimental issues.

In summary, we have shown, on the one hand, the crucial need for coupled-channel approaches in the electromagnetic production of mesons, and on the other hand, confirmed significant contributions from a third S_{11} nucleon resonance to the reaction mechanism.

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